The importance and significance of phase

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Developing Good Practice in Metrology Applications

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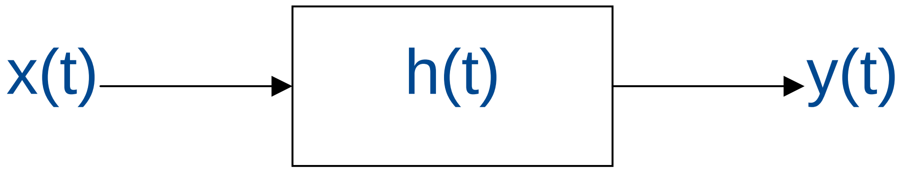
Phase and group delay

- Consider linear, causal, time-invariant system with transfer characteristics H(ω) and impulse response h(t).



Phase and group delay

- The signal at the output of the system has a spectrum: $Y(\omega)=X(\omega)H(\omega)=X(\omega)|H(\omega)|e^{j\varphi(\omega)}$
- In the time domain, each frequency component of the output y(t) is simply a delayed and amplitude-scaled version of the corresponding input signal frequency component.
- The group delay or envelope delay of the system is: $\tau(\omega)=-d\varphi(\omega)/d\omega$
- $\tau(\omega)$ is the time delay that a signal component of frequency ω undergoes as it passes through the system

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The significance of phase

- Linear phase $\rightarrow$ Pure delay
- Nonlinear phase $\rightarrow$ Each frequency component of the signal is delayed by a different amount as it passes through the system

Practical example

- Hydrophone/amplifier magnitude and phase response requirements when estimating acoustic waveform pressure parameters

Hydrophone/amplifier magnitude and phase response

- Ultrasonic imaging remains the most rapidly growing medical imaging modality

- The main method of measurement and characterisation of medical ultrasonic fields propagating in water is through the use of calibrated hydrophones

- NPL provides a calibration of the magnitude response over the frequency range 1-20 MHz

How important is hydrophone phase information when estimating acoustic waveform parameter?

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Objective

- Provide guidelines on importance of the hydrophone phase response when estimating key acoustic waveform parameters (p^+, p^-, t_d and p_i) which will feed into international standards

- Does data have to be corrected for phase?

- If not, what uncertainty does this give rise to?

Key acoustic pressure parameters

- Peak-positive acoustic pressure p^+
- Peak-negative acoustic pressure p^-
- Pulse-pressure-squared integral p_i: time integral of the square of the instantaneous acoustic pressure in the pulse, integrated over the whole of the pulse
- Pulse duration t_d: 1.25 times the interval between the time when the time integral of the instantaneous acoustic pressure squared reaches 10% and 90% of its final value

Commercially available hydrophone investigated

- Marconi 25 μm film thickness, 0.5 mm element diameter bilaminar membrane hydrophone; response obtained from NPL hydrophone model [1].
- Account for uncertainties in magnitude and phase using a Monte Carlo simulation [2].
- Obtain uncertainties in acoustic pressure parameters for specified uncertainties in phase response.

[1]: Gélat PN, Preston RC and Hurrell A, “A theoretical model describing the transfer characteristics of a membrane hydrophone and validation”, Ultrasonics, article in press.

[2]: M.G. Cox and P.M. Harris. The GUM and its planned supplemental guides. Accreditation and Quality Assurance, 8, 375-379, 2003.

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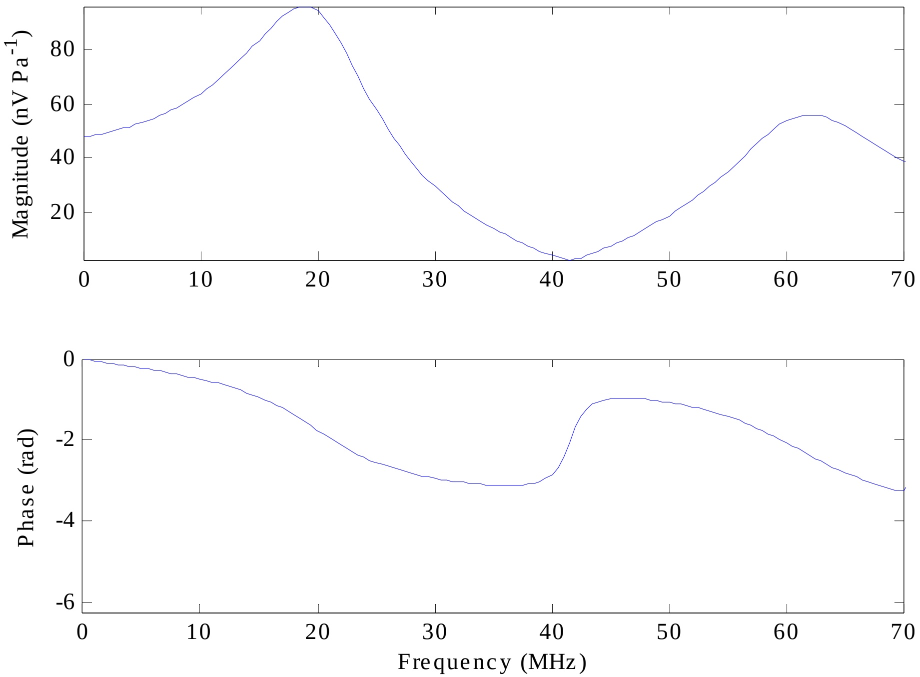
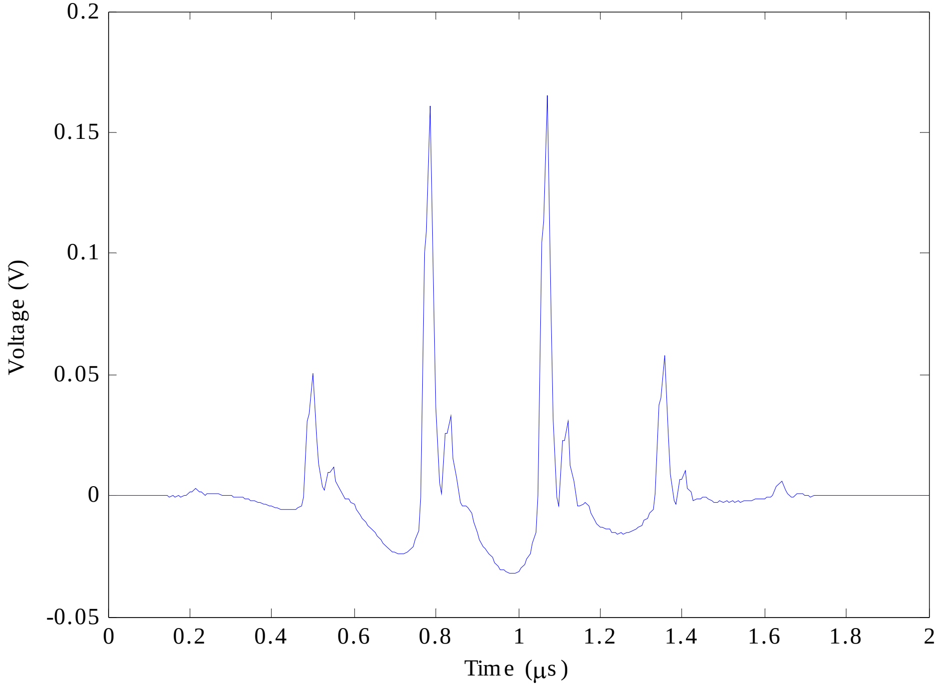
Membrane hydrophone response

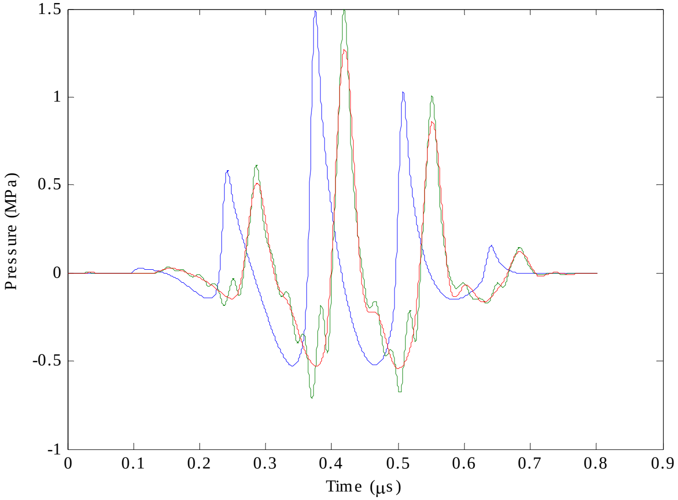


Hydrophone output voltage waveform

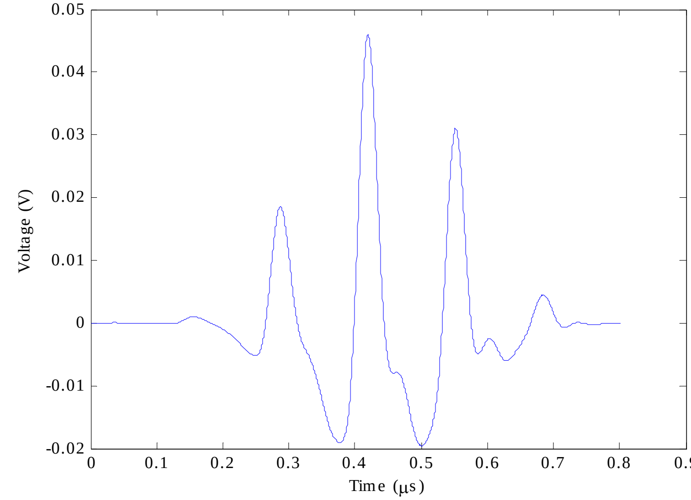


Schematic of deconvolution procedures

Pressure

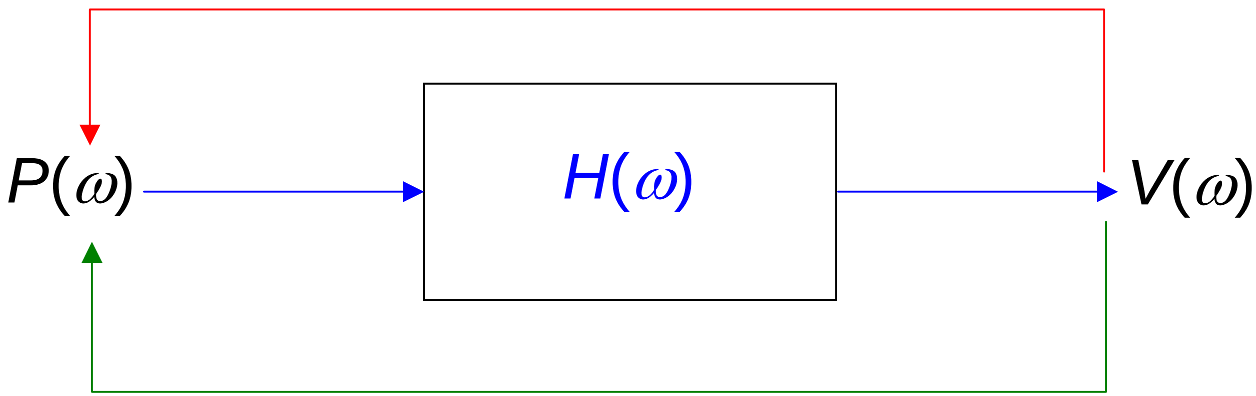


Voltage



Single value at fundamental frequency

$|H(\omega_0)|$



$|H(\omega)|$

Zero Phase

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Procedure for evaluating effect of phase response on deconvolution

- Obtain Fourier transform of output voltage of hydrophone by knowledge of input pressure $p(t)$ and hydrophone/amplifier transfer characteristics $H(\omega)$:

$$V(\omega) = H(\omega)P(\omega)$$

- Pressure waveform can be estimated as follows:

$$\tilde{p}_1(t) = F^{-1}\left(\frac{V(\omega)}{H(\omega)}\right)$$

$$\tilde{p}_2(t) = F^{-1}\left(\frac{V(\omega)}{\left|H(\omega_0)\right|}\right)$$

$$\tilde{p}_3(t) = F^{-1}\left(\frac{V(\omega)}{\left|H(\omega)\right|}\right)$$

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Sample result of Monte Carlo simulation